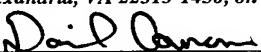


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MAGNETORESISTIVE SPIN-VALVE SENSOR  
AND MAGNETIC STORAGE APPARATUS

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DESCRIPTION

MAGNETORESISTIVE SPIN-VALVE SENSOR  
AND MAGNETIC STORAGE APPARATUS

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TECHNICAL FIELD

The present invention generally relates to magnetoresistive spin-valve sensors and magnetic storage apparatuses, and more particularly to a 10 magnetoresistive spin-valve sensor having a specular layer, and to a magnetic storage apparatus which uses such a magnetoresistive spin-valve sensor.

BACKGROUND ART

15 A typical magnetoresistive spin-valve sensor includes a base layer, a first magnetic (pinned) layer, a spacer layer, and a second magnetic (free) layer which are stacked in this order. By increasing the output of the 20 magnetoresistive spin-valve sensor, it is possible to read information from magnetic recording media having a high recording density.

For example, the use of a highly conductive back layer on the free layer is proposed 25 in a United States Patent No.5,422,571. By the provision of the back layer, the electron mean-free-path is increased due to the so-called "spin-filter effect", thereby increasing the output of the magnetoresistive spin-valve sensor.

30 On the other hand, the use of a specular layer on the free layer is proposed in Egelhoff et al., "Specular electron scattering in metallic thin films", J. Vac. Sci. Technol. B 17(4), Jul/Aug 1999. By the provision of the specular layer, the 35 specularity of conduction electrons is increased, thereby increasing the spin-dependent scattering and the electron mean-free-path. As a result, the

output of the magnetoresistive spin-valve sensor is increased.

It is possible to increase the output of the magnetoresistive spin-valve sensor by decreasing 5 the thickness of the free layer because a magnetic flux density and thickness product, that is, a  $tB_s$  value, decreases accordingly, where  $t$  denotes the thickness of the free layer and  $B_s$  denotes the magnetic flux density of the free layer. However, 10 it is difficult to decrease the thickness of the free layer while maintaining a small coercive field and a small interlayer coupling field  $H_{in}$  between the pinned layer and the free layer, particularly when the specular layer is in direct contact with 15 the free layer.

Alternatively, it is also possible to increase the output of the magnetoresistive spin-valve sensor by decreasing the thickness of the spacer layer because a shunt current which does not 20 contribute to the magnetoresistive effect decreases accordingly. But it is difficult to decrease the thickness of the spacer layer without increasing the interlayer coupling field  $H_{in}$  between the pinned layer and the free layer.

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#### DISCLOSURE OF THE INVENTION

Accordingly, it is a general object of the present invention to provide a novel and useful magnetoresistive spin-valve sensor and magnetic 30 storage apparatus in which the problems described above are eliminated.

Another and more specific object of the present invention is to provide a magnetoresistive spin-valve sensor and a magnetic storage apparatus, 35 which can decrease the thickness of the magnetic layer and/or the spacer layer, while maintaining a small coercive field and a small interlayer coupling

field  $H_{in}$  between a first magnetic (pinned) layer and a second magnetic (free) layer, so that an increased output can be obtained from the magnetoresistive spin-valve sensor.

5 Still another object of the present invention is to provide a magnetoresistive spin-valve sensor comprising a magnetic layer, a specular layer made of a metal oxide, a back layer, made of Au, Cu or an alloy thereof, interposed between the 10 magnetic layer and the specular layer, and a metal layer disposed adjacent to the specular layer, opposite to the back layer, and made of a metal which improves GMR performance of the magnetoresistive spin-valve sensor. According to 15 the magnetoresistive spin-valve sensor of the present invention, it is possible to decrease the thickness of the magnetic layer and/or a spacer layer, while maintaining a small coercive field and a small interlayer coupling field  $H_{in}$  between the 20 magnetic layer and another magnetic layer, so that an increased output can be obtained from the magnetoresistive spin-valve sensor.

A further object of the present invention is to provide a magnetic storage apparatus for 25 reading information from a magnetic recording medium, comprising a magnetoresistive spin-valve sensor which reads the information from the magnetic recording medium, where the magnetoresistive spin-valve sensor comprises a magnetic layer, a specular 30 layer made of a metal oxide, a back layer made of Au, Cu, AuCu, AgCu, AuAgCu or an alloy thereof and interposed between the magnetic layer and the specular layer, and a metal layer disposed adjacent to the specular layer, opposite to the back layer, 35 and made of a metal which improves GMR performance of the magnetoresistive spin-valve sensor. According to the magnetic storage apparatus of the

present invention, it is possible to decrease the thickness of the magnetic layer and/or a spacer layer of the magnetoresistive spin-valve sensor, while maintaining a small coercive field and a small 5 interlayer coupling field  $H_{in}$  between the magnetic layer and another magnetic layer, so that an increased output can be obtained from the magnetoresistive spin-valve sensor. As a result, it is possible to read information from a high-density 10 magnetic recording medium.

Other objects and further features of the present invention will be apparent from the following detailed description when read in conjunction with the accompanying drawings.

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#### BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a cross sectional view showing the general structure of an important part of a first embodiment of a magnetoresistive spin-valve 20 sensor according to the present invention;

FIG. 2 is a diagram for explaining compensation of magnetic fields in the first embodiment;

FIG. 3 is a diagram showing a back layer 25 thickness dependence of a change in sheet resistance in the first embodiment;

FIG. 4 is a diagram showing a back layer thickness dependence of an interlayer coupling field  $H_{in}$  in the first embodiment;

30 FIG. 5 is a diagram showing a GMR performance and a change in sheet resistance for a case where the back layer is made of a Cu alloy and a metal capping layer is made of Ta in the first embodiment;

35 FIG. 6 is a diagram showing a GMR performance and a change in sheet resistance for a case where the back layer is made of a Cu alloy and

the metal capping layer is made of Ta in the first embodiment;

FIG. 7 is a cross sectional view showing the general structure of an important part of a second embodiment of the magnetoresistive spin-valve sensor according to the present invention;

FIG. 8 is a cross sectional view showing the general structure of an important part of a third embodiment of the magnetoresistive spin-valve sensor according to the present invention;

FIG. 9 is a cross sectional view showing an important part of an embodiment of a magnetic storage apparatus according to the present invention; and

FIG. 10 is a plan view showing the important part of the embodiment of the magnetic storage apparatus.

BEST MODE OF CARRYING OUT THE INVENTION

FIG. 1 is a cross sectional view showing the general structure of an important part of a first embodiment of a magnetoresistive spin-valve sensor according to the present invention. The magnetoresistive spin-valve sensor shown in FIG. 1 generally includes a substrate 1, an underlayer 2, an antiferromagnetic layer 3, a first magnetic layer 4, a spacer layer 5, a second magnetic layer 6, a back layer 7, a specular layer 8, and a metal capping layer 9.

The first magnetic layer 4 is made of a magnetic material such as a Co-based alloy, and may have a single-layer structure or a multi-layer structure. The first magnetic layer 4 forms a pinned layer of the magnetoresistive spin-valve sensor. The spacer layer 5 is made of a nonmagnetic metal such as Cu. The second magnetic layer 6 is made of a soft magnetic material such as a Co-based

alloy, and forms a free layer of the magnetoresistive spin-valve sensor. The second magnetic layer 6 may have a single-layer structure or a multi-layer structure. The back layer 7 is 5 made of Au, Cu, AuCu, AgCu, AuAgCu or an alloy thereof. The back layer 7 may be made of a  $Au_{1-x}Cu_x$  alloy,  $Ag_{1-x}Cu_x$  alloy,  $Au_{1-x-y}Ag_yCu_x$  alloy, where x denotes a fraction of Cu in the alloy, y denotes a fraction of Ag in the alloy, and x and y 10 respectively are greater than 0.0 and less than 1.0 so that  $x+y$  is less than 1.0. The specular layer 8 is made of a material selected from a group of CoO,  $Co_3O_4$ ,  $Co_2O_3$ ,  $Cu_2O$ , CuO,  $Al_2O_3$ , NiO, FeO,  $Fe_2O_3$ , MnO,  $TiO_2$  and alloys thereof. Further, the metal capping 15 layer 9 is made of a material selected from a group of Ta, Ru, Ni, Fe, Pd, Pt, Mn, Cu, Co, Ti, V, Cr, Zn, Y, Zr, Nb, Mo, Rh, Ag, Au, Hf, W, Re, Os, Ir, Nb and alloys thereof.

Because the back layer 7 between the 20 second magnetic layer 6 and the specular layer 8, the so-called spin-filter effect and an enhanced specularity of conduction electrons at the interface between the back layer 7 and the specular layer 8 are obtained. As a result, a high GMR effect can be 25 obtained. In addition, the thickness of the second magnetic layer 6 can be controlled to a small value while keeping a low coercivity of the second magnetic layer 6, since the back layer 7 separates the second magnetic layer 6 from direct contact with 30 the specular layer 8. The back layer 7 also decreases the interlayer coupling field  $H_{in}$  between the first and second magnetic layers 4 and 6, since electron reflections can be affected at the interfaces, as may be readily understood from de 35 Vries et al., "Oscillatory interlayer exchange coupling with the Cu cap layer thickness in Co/Cu/Co/Cu(100)", Phys. Rev. Lett., Vol. 75, pp. 4306,

1995.

The back layer 7 also makes a bias point easy to control, because a magnetic field  $H_{msb}$  from the back layer 7 is opposite to a magnetic field  $H_s$  from the spacer layer 5, as may be seen from FIG. 2. FIG. 2 is a diagram for explaining compensation of the magnetic fields in this first embodiment. In FIG. 2, the left portion shows an important part of this first embodiment, and the right portion shows the magnetic fields  $H_{msb}$  and  $H_s$  by a bold arrow and a phantom arrow, respectively, when a sense current is applied to the magnetoresistive spin-valve sensor. Moreover,  $I_{msb}$  denotes a current through the back, specular and metal cap layers 7, 8 and 9, and  $I_s$  denotes a current through the spacer layer 5.

Therefore, enhanced specularity at the interface between the back layer 7 and the specular layer 8, extended electron mean-free-path from the spin-filter effect, and easy control of the bias point significantly increase the output of the magnetoresistive spin-valve sensor.

FIG. 3 is a diagram showing a back layer thickness dependence of a change in sheet resistance in this first embodiment. In FIG. 3, the ordinate indicates a change in sheet resistance  $\Delta R$  ( $\Omega$ ), and the abscissa indicates a thickness  $t$  ( $\text{\AA}$ ) of the back layer 7. For the sake of convenience, the second magnetic layer 6 has a thickness of 40  $\text{\AA}$ , and the specular layer 8 has a thickness of 15  $\text{\AA}$ . The change in sheet resistance  $\Delta R$  is a difference between maximum and minimum values of the sheet resistance  $R$ , and may be used to evaluate the performance of the magnetoresistive spin-valve sensor since the change in sheet resistance  $\Delta R$  is approximately proportional to the output of the magnetoresistive spin-valve sensor. As may be seen from FIG. 3, the change in sheet resistance  $\Delta R$

increases by approximately 60% when the thickness  $t$  of the back layer 7 is less than approximately 20 Å.

FIG. 4 is a diagram showing a back layer thickness dependence of the interlayer coupling

5 field  $H_{in}$  in this first embodiment. In FIG. 4, the ordinate indicates the interlayer coupling field  $H_{in}$  (Oe), and the abscissa indicates thickness  $t$  (Å) of the back layer 7. For the sake of convenience, the second magnetic layer 6 has a thickness of 40 Å,  
10 and the specular layer 8 has a thickness of 15 Å. As may be seen from FIG. 4, the interlayer coupling field  $H_{in}$  decreases by more than approximately 90% and stays under approximately 10 Oe when the thickness  $t$  of the back layer 7 is less than  
15 approximately 20 Å.

From FIGS. 3 and 4, it was confirmed that the GMR performance of the magnetoresistive spin-valve sensor degrades due to a significant shunting current through the back layer 7 when the back layer  
20 7 has a thickness exceeding approximately 20 Å.

Although conventionally difficult to achieve, it was confirmed that this first embodiment can suppress the interlayer coupling field  $H_{in}$  to approximately 20 Oe or less even when the thickness  
25 of the second magnetic layer 6 is 40 Å or less. In other words, it was confirmed that the output of the magnetoresistive spin-valve sensor can be increased even when an effective thickness of the second magnetic layer 6, excluding a thickness of a  
30 magnetically dead layer, is greater than 0 and less than approximately 40 Å. Therefore, this first embodiment can control the thickness of the second magnetic layer 6 while keeping soft magnetic properties, and the coercivity and the interlayer  
35 coupling field  $H_{in}$  can be suppressed to approximately 20 Oe or less.

FIGS. 5 and 6 respectively are diagrams

showing a GMR performance and a change in sheet resistance for cases where the back layer 7 is made of Cu alloys and the metal capping layer 9 is made of Ta in this first embodiment. In FIGS. 5 and 6, a 5 symbol "●" indicates the GMR performance, and a symbol "○" indicates the change in sheet resistance.

In FIG. 5, the right ordinate indicates the GMR performance (%) of the magnetoresistive spin-valve sensor, the left ordinate indicates the 10 change in sheet resistance  $\Delta R$  ( $\Omega$ ), the abscissa indicates the Cu or Cu alloy used for the back layer 7, and the metal capping layer 9 has a thickness of 50 Å. In FIG. 6, the right ordinate indicates the 15 GMR performance (%) of the magnetoresistive spin-valve sensor, the left ordinate indicates the change in sheet resistance  $\Delta R$  ( $\Omega$ ), the abscissa indicates the Cu alloy used for the back layer 7, and the metal capping layer 9 has a thickness of 10 Å.

As may be seen from FIGS. 5 and 6, it was 20 confirmed that the MSR performance is further improved when the AgCu or AuCu alloy is used for the back layer 7, compared to the case where Cu is used for the back layer 7. In addition, as may be seen from FIG. 6, it was observed that the 10 Å thick 25 metal capping layer 9 simulates the specular layer 8, even though the specularity seems to be small. It was also observed that the use of  $Ag_{11}Cu_{89}$  or  $Au_{9.2}Cu_{90.8}$  for the back layer 7, for example, especially improves the properties of the spin-valve 30 sensor. It was also confirmed that the interlayer coupling field  $H_{in}$  and the coercivity  $H_c$  do not change greatly with a change in the composition of the back layer 7, and remain at small values which is necessary for obtaining a high output from the 35 spin-valve sensor.

In addition, the metal capping layer 9 protects the specular layer 8 and the second

magnetic layer 6 from chemically, physically, mechanically and thermally harsh environments during the fabrication process. As a result, degradation of the electrical and magnetic properties of the 5 magnetoresistive spin-valve sensor caused during the fabrication process is prevented in this first embodiment, and the metal capping layer 9 positively improves GMR performance of the magnetoresistive spin-valve sensor, in addition to simply protecting 10 the second magnetic layer 6 by a capping function.

For example, a Japanese Laid-Open Patent Application No.10-313138 proposes a metal capping layer made of various metals, but the metal capping layer is merely provided to protect a magnetic layer 15 disposed underneath, and does not improve the GMR performance of a magnetoresistive spin-valve sensor.

Therefore, the arrangement of the second magnetic layer 6, the back layer 7, the specular layer 8 and the metal capping layer 9 as shown in 20 FIG. 1 generates the following advantageous features. First, the back layer 7 prevents further diffusion of oxygen into the adjacent second magnetic layer 6 during deposition of the specular layer 8 during the fabrication process, so that the coercivity of the 25 second magnetic layer 6 remains less than approximately 20 Oe. Second, because the back layer 7 is highly conductive in the magnetoresistive spin-valve sensor, the electron mean-free-path increases due to the spin-filter effect, to thereby increase 30 the output of the magnetoresistive spin-valve sensor. Third, the interface between the back layer 7 and the specular layer 8 increases the specularity of the conduction electrons, which increases the 35 possibility of the spin-dependent scattering, which thereby also results in an increase in the output of the magnetoresistive spin-valve sensor.

FIG. 7 is a cross sectional view showing

the general structure of an important part of a second embodiment of the magnetoresistive spin-valve sensor according to the present invention. In FIG. 7, those parts which are the same as those 5 corresponding parts in FIG. 1 are designated by the same reference numerals, and a description thereof will be omitted.

In the first embodiment described above, the structure shown in FIG. 1 is provided at a top 10 portion of the magnetoresistive spin-valve sensor. On the other hand, in this second embodiment, the structure shown in FIG. 7 is embedded inside the magnetoresistive spin-valve sensor. In this second embodiment, the magnetoresistive spin-valve sensor 15 has an inverted structure as compared to that of the first embodiment, and the layers are disposed in a reverse order to that of the first embodiment.

FIG. 8 is a cross sectional view showing the general structure of an important part of a 20 third embodiment of the magnetoresistive spin-valve sensor according to the present invention. In FIG. 8, those parts which are the same as those corresponding parts in FIG. 1 are designated by the same reference numerals, and a description thereof 25 will be omitted.

In the first embodiment described above, the structure shown in FIG. 1 is provided at a top portion of the magnetoresistive spin-valve sensor. On the other hand, in this third embodiment, the structure shown in FIG. 7 is embedded inside the magnetoresistive spin-valve sensor. In this third embodiment, the magnetoresistive spin-valve sensor 30 has an inverted structure as compared to that of the first embodiment, and the layers are disposed in a reverse order to that of the first embodiment.

Furthermore, in this third embodiment, a metal underlayer 9-1 is provided under the specular

layer 8. The metal underlayer 9-1 can provide the rest of the magnetoresistive spin-valve sensor with a good crystallographic texture, so that the electrical and magnetic properties of the 5 magnetoresistive spin-valve sensor are improved thereby. Particularly, the soft magnetic properties of the second magnetic layer 6 improve due to the crystallographic texture thereof which is improved by the provision of the metal underlayer 9-1.

10 In each of the embodiments described above, the second magnetic layer 6 may form the free layer or any magnetically responding layer of the magnetoresistive spin-valve sensor.

15 Next, a description will be given of an embodiment of a magnetic storage apparatus according to the present invention, by referring to FIGS. 9 and 10. FIG. 9 is a cross sectional view showing an important part of this embodiment of the magnetic storage apparatus, and FIG. 10 is a plan view 20 showing the important part of this embodiment of the magnetic storage apparatus.

As shown in FIGS. 9 and 10, the magnetic storage apparatus generally includes a housing 113. A motor 114, a hub 115, a plurality of magnetic 25 recording media 116, a plurality of recording and reproducing heads 117, a plurality of suspensions 118, a plurality of arms 119, and an actuator unit 120 are provided within the housing 113. The magnetic recording media 116 are mounted on the hub 30 115 which is rotated by the motor 114. The recording and reproducing head 117 is made up of a reproducing head and a recording head such as an inductive head. Each recording and reproducing head 117 is mounted on the tip end of a corresponding arm 35 119 via the suspension 118. The arms 119 are moved by the actuator unit 120. The basic construction of this magnetic storage apparatus is known, and a

detailed description thereof will be omitted in this specification.

This embodiment of the magnetic storage apparatus is characterized by the reproducing head 5 of the recording and reproducing head 117. The reproducing head has the structure of any of the first through third embodiments of the magnetoresistive spin-valve sensor described above in conjunction with FIGS. 1 through 8. Of course, 10 the number of magnetic recording media 116 is not limited to three, and only one, two or four or more magnetic recording media 116 may be provided. Consequently, one of a plurality of magnetoresistive 15 spin-valve sensors may be provided depending on the number of recording and reproducing heads 117 provided.

The basic construction of the magnetic storage apparatus is not limited to that shown in FIGS. 9 and 10. In addition, the magnetic recording 20 medium used in the present invention is not limited to magnetic disk.

Further, the present invention is not limited to these embodiments, but various variations and modifications may be made without departing from 25 the scope of the present invention.